



Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Study of the structure of inter-organization innovation network based on grey relational analysis

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ABSTRACT

Inter-organization cooperation and innovation is increasingly common. However as the limitation of information, the members in the innovation network cannot evaluate each other when they need to choose cooperators. In this paper, a new type of inter-organization innovation network which comprises preferential attachment and preferential deletion based on grey relational analysis is studied. A series of simulations and analysis of average path length and clustering coefficient are conducted. To be specifically, grey relational analysis can help organizations in choosing cooperators. By simulation analysis, we compare the inter-organization innovation network in the steady state based on grey relational analysis with the random network and regular network, we find that such innovation network has the property of 'small world', which can demonstrate that evolution model of innovation network based on grey relational analysis is reasonable.

Keywords: innovation network, network structure, small-world, grey relational analysis, inter-organization.

INTRODUCTION

Networks are ubiquitous in nature and society, describing various complex systems, such as the Internet, food webs, or blood vessels[1]. Despite their diversity, most networks appearing in nature follow universal organizing principles. Particularly, many networks are 'small-world', which are highly clustered and having small path lengths[2]. The high interest in understanding the topology of complex networks has resulted in the development of a considerable number of network models.

Watts and Strogatz (1998) found that real systems are highly clustered, like regular lattices, yet have small characteristic path lengths, like random graphs, i.e., 'small-world' networks[2]. They consider the following random rewiring procedure: starting from a ring lattice with n nodes and k edges per node, they rewire each edge at random with probability p . This construction allows us to 'tune' the graph between regularity ($p = 0$) and disorder ($p = 1$), and thereby to probe the intermediate region $0 < p < 1$. They discover that for small p the network has the 'small-world' phenomenon.

However, the rewiring probability couldn't be random, which may not only depend on the connectivity of those nodes but also on the relevance with each other. How to rank the relevance with the members is a difficult problem. Grey relational degree analysis can determine the relevance between different organizations with less information available.

Recently the research on innovation network has developed rapidly. Several literatures have proposed the

construction of such network[3, 4]. However, they ignore the fact that the members in the innovation network can not derive fully information to evaluate each other when they need to choose cooperators. They often derive little information. How to solve this problem? Grey system theorem is used to determine the unknown system by little known information which is proposed by Professor Deng Julong in 1982[5]. There are no strict requirements of the sample size and the sample distribution. At present, grey system theorem has a wide range of applications in many fields[6, 7], however little research has been made in the applications of complex network.

In this paper, we construct the evolution model of innovation network mainly based on grey relational analysis which is devoted to study and deal with complex system by not completeness information. Each time organizations in the innovation network need to evaluate the members in the network with little known information. Then each organization decides the cooperators in the next time by the grey relational degree analysis and connectivity rather than by random selection which is much more close to the reality. By simulations, we derive that the innovation network in the steady state has the property of 'small-world'. In reality, such innovation network really has the 'small-world' property which can demonstrate that evolution model of innovation network based on grey relational analysis is reasonable.

2. Evolution model based on grey relational analysis

2.1 Description of some notations

Let $N = \{1, 2, \dots, n\}$ denote a finite set of organizations in the innovation network. For any $i, j \in N$, define the binary variable $\chi_t(i, j)$ to take the value $\chi_t(i, j) = 1$ if a connection exists between i and j in period t , and $\chi_t(i, j) = 0$ otherwise. If two organizations are willing to innovate together, then there exists a connection between the two. The set of organization i 's all collaborators in period t can be defined by $\Gamma_{i,t} = \{j \in N \mid \chi_t(i, j) = 1\}$. The number of organization i 's all collaborators in period t can be defined by $k_{i,t} = \sum_{j \in N} \chi_t(i, j)$, which can also be called the degree of organization i .

Each organization in the innovation network has a certain feature set which is related to industry property, development direction and so on. Suppose each feature vector is characterized by K indicators. Sometimes the indicators are time serial numbers or index numbers and x_i denotes organization i 's feature vector. We represent this as a vector of length $K \geq 2$, which allows us to think of each organization as located at a point in the feature space.

2.2 Construction of the evolution model

We will construct the evolution model of the inter-organization innovation network based on grey relational analysis in this section.

Following is the evolution algorithm of the innovation network.

Step 0 Initialization.

As the organizations initially may not be familiar with each other in the innovation network, suppose each organization chooses those who are nearest to it to cooperate in the initial time[8, 9].

Step 1 Evaluation process.

In period t , organization i need to evaluate all the other members in the innovation network, such as from the view of relevance with itself. Take an example with organization j ($j \in N$ and $j \neq i$), according to the grey relational analysis, the correlation between organization i and organization j ($j \in N$ and $j \neq i$) are evaluated. To be specifically, the grey relational coefficient between x_i and x_j ($i, j = 1, \dots, n, i \neq j$) at the indicator of k is defined as

$$\varepsilon_{i,j}(k) = \frac{\min_j \min_k |x'_i(k) - x'_j(k)| + \xi \max_j \max_k |x'_i(k) - x'_j(k)|}{|x'_i(k) - x'_j(k)| + \xi \max_j \max_k |x'_i(k) - x'_j(k)|} \quad (1)$$

where ξ is a distinguishing coefficient for controlling the resolution scale which range from 0 to 1 and is normally taken as 0.5, and $x'_i(k)$ is defined by

$$x'_i(k) = \frac{x_i(k) - \min_i x_i(k)}{\max_i x_i(k) - \min_i x_i(k)} \quad (2)$$

By Eq.(2) we can transfer $x_{i,t}(k)$ into $[0,1]$, $x'_{i,t}(k)$ is the interval value of $x_i(k)$ and has no dimensions[10].

The grey relational degree between organization i and organization j is obtained as follows

$$\gamma_{i,j} = \frac{1}{n} \sum_{k=1}^n \varepsilon_{i,j}(k), \quad i, j = 1, \dots, n, i \neq j \quad (3)$$

Step 2 Preferential attachment.

In reality, the organizations are willing to collaborate with those much richer or much more relevant[11, 12]. One example is Apple Inc. which has a large number of cooperators such as suppliers, developers, OEMs and so on. Maybe many companies in the world are still willing to cooperate with it other than cooperate with those having few cooperators. Another example is mobile phone manufacturers, they may cooperate with operators and software developers. There is less possibility for mobile phone manufacturers to cooperate with medical teams or housekeeping servers. As for the limitation of information acquirements and communication capability, organizations in the network may not grasp the whole members' information. Most cases, it only obtains a part of them.

In period $t+1$, organization i decides to cooperate with organization j in the innovation network using a preferential attachment with probability $P_{ij,t+1}^a$, which is defined by

$$P_{ij,t+1}^a = \frac{\gamma_{i,j} k_{j,t} + a}{\sum_{j \in N} \gamma_{i,j} \sum_{j \in N} (k_{j,t} + a)} \quad (4)$$

where $k_{j,t}$ denotes the degree of the organization j in period t and $a(\geq 0)$ is a constant here we call it tunable parameter. In the original Barabási–Albert scale-free model, a is equal to zero[12]. Here we use grey relational degree to analyze the correlation between different nodes.

Eq.(4) means that the organization may cooperate with those which have higher relevance with itself or have more cooperators in the innovation network.

Step 3 Preferential deletion.

As the organization's ability is limited, to establish a cooperative relationship between organizations should pay a certain cost, such as time cost, energy cost and psychological cost. The number of organization's collaborators could not increase without limit. On the other hand, the organizations do not randomly select the abandon one[13]. Usually they make a judgment based on their collaborators' market share, development prospects and so on. For example, before 2007 Apple Inc. had been using the chips of IBM. However for the IBM chips' heat dissipation problems as well as the performance of the recession, Apple eventually "abandoned" the cooperator IBM who had cooperated with it for ten years to establish cooperation with Intel.

Thus this paper assumes that if an organization decides to cooperate with a "new" organization, it will selectively "abandon" one of the original partners. Suppose in period $t+1$, organization i gives up one of its partners in period t , such as organization j , with the probability $P_{ij,t+1}^d$, which is defined by

$$P_{ij,t+1}^d = \left(1 - \frac{(k_{j,t} + a)\gamma_{i,j}}{\sum_{j \in \Gamma_{i,t}} (k_{j,t} + a)\gamma_{i,j}}\right) / (k_{i,t} - 1) \quad (5)$$

where $\Gamma_{i,t} = \{j \in N \mid \chi_i(i, j) = 1\}$ and $\gamma_{i,j}$ is the grey relational degree between organization i and organization j .

Eq.(5) means that the organization may abandon those which have lower relevance with itself or have fewer cooperators in the innovation network.

Step 4 Evolution mechanism.

If all the organizations in the innovation network are unwilling to change their partners, we call the network reaches the steady state.

Every time, choose one organization to change its partners according to step 2 and step 3. Then go to Step 1-3 until the innovation network reaches the steady state.

2.3 Analysis of the evolution model

2.3.1 Some definitions

Path length measures the typical separation between two nodes in the network. Average path length L is defined as the number of edges in the shortest path between two nodes, averaged over all pairs of nodes.

$$L = \frac{1}{N(N-1)} \sum_{i \neq j \in S} d_{ij}$$

where d_{ij} is the shortest distance between node i and node j [14].

The clustering coefficient C is defined as follows.

Suppose that a node i has k_i neighbors, then at most $k_i(k_i-1)/2$ edges can exist between them (this occurs when every neighbor of i is connected to every other neighbor of i). Let C_i denote the fraction of these allowable edges that actually exist.

$$C_i = \frac{2E_i}{k_i(k_i-1)}$$

where E_i denote the actual number of edges.

Define clustering coefficient C as the average of C_i over all i [14]

$$C = \frac{1}{N} \sum_{i=1}^N C_i$$

2.3.2 Data selection and processing

In this section, the original data are randomly generated. We choose eight indicators from 50 organizations to reflect the relevance (K_i , $i=1,2,\dots,8$), where K_1 -R&D Investment, K_2 -personnel number of R&D, K_3 -activities of R&D, K_4 -proportion of R&D investment in sales revenue, K_5 -number of patent application, K_6 -number of holding patents, K_7 -sales revenue of new products, and K_8 -proportion of sales revenue of new products in all sales revenue. In fact, each data can be the average over time. As each data cannot be compared directly, we need to dimensionless the original data. It is noted that different generation results of original data will not affect the representation of the following simulation results.

Set $\xi = 0.5$ and the weights of each index are equal to (0.16, 0.13, 0.08, 0.11, 0.07, 0.24, 0.10, 0.11) by using expert investigation method. Then we can compute the grey relational degree between each organization.

Due to space limitation, here we only give the grey relational coefficient between organization 1 and other organizations, that is to say we need to take x_1 as a system characteristic sequence. The results are 0.6344, 0.7208, 0.6226, 0.6224, 0.5473, 0.6549, 0.7549, 0.6020, 0.5871, 0.6737, 0.5340, 0.5793, 0.5749, 0.5729, 0.6074, 0.5665, 0.7344, 0.6750, 0.6250, 0.6915, 0.6791, 0.7218, 0.7780, 0.6765, 0.6279, 0.7576, 0.7178, 0.6557, 0.6797, 0.6821, 0.6629, 0.6271, 0.6193, 0.7279, 0.5896, 0.5373, 0.6406, 0.5758, 0.5981, 0.6415, 0.7075, 0.6641, 0.6925, 0.6347, 0.6150, 0.6464, 0.6080, 0.6328, 0.6099.

Suppose in the initial time the scale of the innovation network is 50. We choose each node to its nearest 8 neighbors in a clockwise sense which forms a regular network. Parameter a is equals to one. The initial network is

shown in Figure 1.

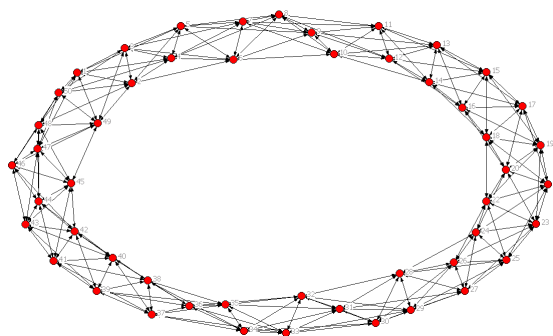


Figure1. Network structure under the initial state (regular network)

2.3.3 Simulation analysis

Average path length and clustering coefficient are two important indicators to analyze whether the network has 'small world' properties. We know regular network has larger average path length and clustering coefficient, while the random network has smaller ones[15]. Generally, if the network's clustering coefficient is far greater than random network's and average path length is equivalent to random network's, then the network has the 'small world' phenomenon[16].

Figure 2 shows the network structure generated by grey relational analysis under the steady state. Table 1 compares the network with the regular network and random network. We derive that the average path length produced by our model is only slightly larger than the random network's which is calculated by $L_R = \frac{\log(N)}{\log(\langle k \rangle)}$. On the other hand, the clustering coefficient by our model is far greater than the clustering coefficient of the random network's which is calculated by $C_R = \frac{\langle k \rangle}{N}$. Thus the network structure under the steady state has the property of 'small-world'.

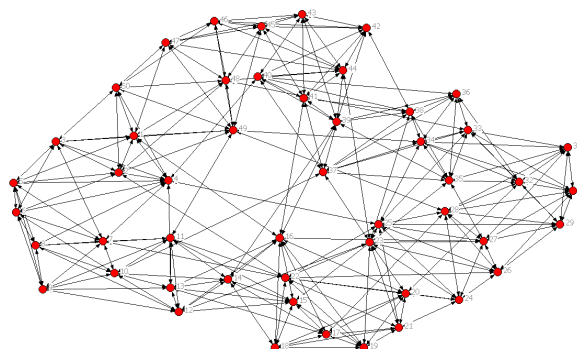


Figure 2. Network structure under the steady state (small-world network)

Table 1. The comparisons of the three networks

Network Indicator	Innovation network	Random network	Regular network
Average path length	2.229	1.8813	3.571
Clustering coefficient	0.53	0.16	0.643

CONCLUSION

Inter-organization cooperation and innovation is increasingly common. A great deal of literatures has proposed the construction of such network. Usually they suppose that the members in the innovation network can derive fully information to evaluate each other when they need to choose cooperators. However this situation is seldom possible. We know grey system theorem can be used to determine the unknown system by little known information

which is proposed by Professor Deng Julong in 1982. There are no strict requirements of the sample size and the sample distribution.

At present, grey system theorem has a wide range of applications in many fields. In this paper, we try to build inter-organization innovation network model by means of grey relational analysis and analyze the structural characteristics of innovation network by the method of computer simulation. It is found that the innovation network in the steady state has the property of 'small-world', although we suppose it is the regular network in the initial time. In fact the innovation network in the reality indeed has such property. That is to say grey system theorem can be used for the analysis of complex network. In further study, we will proceed to consider the application of grey system theory in complex network.

Acknowledgements

This work is supported by Ministry of Education, Humanities and Social Science Project (13YJC630018), National Natural Science Foundation of China (71171116), Jiangsu Province Government Grant to Study Abroad and the Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD) .

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